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TEST OF A MECHANICAL FILTER.

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WITH DISCUSSION.

The object of this paper is to describe briefly the results of a three-months' test of a mechanical filter, which has recently been installed for the East Providence Water Company, at East Providence, R. I.

The New York Filter Manufacturing Company, of New York City, furnished the filter, which is of a type known as the Jewell Gravity Filter.

The entire work, including the filter house and pure-water well, shown on Plate IV, Figs. 1 and 2, was designed and built under the direction of the writer, who acted as Consulting Engineer for the New York Filter Manufacturing Company.

The average daily quantity of water furnished to its consumers by the East Providence Water Company, at the present time, is about 200 000 galls. The available daily capacity of the filter is 500 000 galls., and the rate of filtration 125 000 000 galls. per acre per 24 hours. The filter house, pure-water well and pipes are arranged for a future addition of three more filters of the same design and capacity, when demanded by the requirements of the service.

The filter was run throughout the test under ordinary working conditions, and the filtered water was pumped directly into the mains and supplied to the consumers. The filter was in charge, under the writer's direction, of the regular pumping engineer of the East Providence Water Company. The writer gave directions from time to time, but did not, on the average, visit the filter plant more than once a week during the test.

The chemical analyses were made by Professor John Howard Appleton, of Brown University. The bacteriological work was done by Dr. Gardner T. Swarts, Secretary of the State Board of Health of Rhode Island, who also determined the color and alkalinity of the samples.

The samples of water for analysis were collected by the pumping engineer at about 8 o'clock in the morning, the filter-bed generally being washed about two hours earlier.

In a report, dated March 12th, 1894, describing experiments with experimental filters, made under the writer's direction, in Providence, from February, 1893, to January, 1894, inclusive, the writer's conclusions are given to the effect that water can be as satisfactorily purified by first-class mechanical filtration as by slow sand filtration.

Since this report was published, elaborate investigations, made with mechanical filters, at Louisville, Pittsburg and Cincinnati, with waters widely different from the water supply of Providence, have practically substantiated the writer's conclusions, as given in the Providence report. It would seem, therefore, that after taking into consideration the additional experimental results given in this paper, which were obtained with a filter absolutely in practical service, as though there could no longer be any reasonable doubt, if such may have existed, in regard to the practicability and efficiency of mechanical filtration, and that henceforth, in the broad field of water purification, mechanical filtration can be looked upon as being equally as desirable as slow sand filtration.

The chemical used during the test was sulphate of alumina, which was added to the raw water in the form of a coagulant solution, prepared by dissolving one part of sulphate of alumina in about 20 parts of filtered water. The solution was always thoroughly mixed before being used.

FIG. 1.—FILTER HOUSE, EAST PROVIDENCE WATER COMPANY.

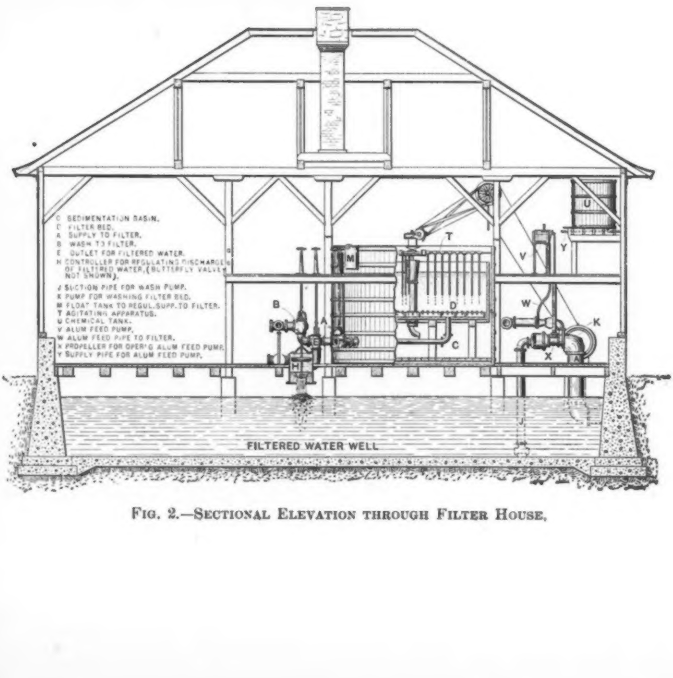

FIG. 2.—SECTIONAL ELEVATION THROUGH FILTER HOUSE.

The theory of mechanical filtration, when sulphate of alumina has been added to the filtered water, may be described briefly as follows: The alumina causes an artificial precipitation; a portion of the alumina is decomposed, forming sulphates of other bases and a flocculent precipitate of aluminic hydrate. A portion of it also combines directly with the organic matter in the water, coagulating the same and thus helping to increase the precipitation. The degree of color of the water is also largely reduced by the uniting of the precipitated aluminic hydrate with the coloring matter in the water.

The filter was first put in service on February 25th, 1899, and it has been in regular operation since that time. The test was commenced on March 13th, which was as soon as a known grade of sulphate of alumina could be procured. Previous to March 13th, sulphate of an inferior grade was used, and was added to the raw water at rates of from $\frac{1}{2}$ to $\frac{3}{4}$ grain per gallon. This was the only quality of sulphate of alumina which could be purchased in Providence at the time, and the percentage of $Al_2 O_3$ which it contained was not known.

The sulphate of alumina used during the test and special experiments, contained about 22% of $Al_2 O_3$, with the exception that during one special experiment an inferior and cheaper grade containing about 17.53% of $Al_2 O_3$ was used.

The sulphate of alumina was added to the raw water at the rate of 1 grain per gallon, with the exception that in three special experiments $\frac{3}{4}$, $\frac{6}{10}$ and $\frac{3}{4}$ grain per gallon were used.

Tables Nos. 1, 2, 3 and 4 give all the results obtained during the test, with the exception of those of the special experiments, which are given in Table No. 5.

As can be seen by Tables Nos. 2, 3 and 4, the investigations relative to the chemical constituents and the color and alkalinity of the samples were concluded on May 31st.

It is the intention to continue the bacteriological analyses, at least until June 30th, 1899, and Table No. 1 gives all the results which have been obtained in time to be made use of in this paper, with the exception of those of the special experiments.

Fig. 1, Plate IV, is a view of the filter house, which is located adjacent to the pumping station of the East Providence Water Company, at "Hunt's Mills." On the right of the plate can be seen a small portion of one end of the pumping station. The power required

for driving the agitator and wash pump is furnished by a turbine wheel located in the basement of the pumping station, and is transmitted to the filter house as shown on the plate.

Fig. 2, Plate IV, is a sectional elevation through the filter, filter house and pure-water well. The filter and auxiliaries comprise a sedimentation basin, a crushed quartz filter-bed having an area of about 176 sq. ft., a pump for adding the coagulant to the raw water, an automatic controller connected to the main discharge pipe of the filter for maintaining a constant rate of filtration, a pump and appliances for washing and agitating the filter-bed and for washing out the sedimentation basin, and screens connected to collecting pipes at the bottom of the filter-bed. The raw water, to which the sulphate of alumina has been added, enters the sedimentation basin through the valve on the supply pipe at *A*, and is deflected by a curved casting in such a manner that it is caused to circulate slowly around the basin. The water rises from the sedimentation basin through the central pipe shown in Fig. 2, Plate IV, to the required height above the filter-bed. The water passes downward and outward through the filter-bed, screens and collecting pipes to the main discharge pipe and controller, during the process of filtration, and inward and upward through the collecting pipes, screens and filter-bed, when the filter-bed is being washed. The screens prevent the quartz or any foreign substances from entering the collecting pipes and passing off with the filtered water.

The depth of the crushed quartz filter-bed is about 3.67 ft. The sedimentation basin has a capacity equal to a flow of about 17 minutes when the filter is being operated at the normal rate of 125 000 000 galls. per acre per 24 hours.

The coagulant pump is made of vulcanized rubber, and consists of six hollow arms radiating from a chambered hub, and bent in the direction of rotation. It is actuated by a propeller, situated in the main supply pipe, by the aid of an upright shaft and bevel gears. The pump gives excellent satisfaction, and its displacement is remarkably accurate.

The automatic controller is of a new and original design, and is a decided success. A careful test of the controller was made when it was first put in service, the flow of water being gauged accurately, and it was found, during a five-hour run of the filter, that the vari-

ation in the rate of filtration between the commencement and the end of the run was less than one-half of 1 per cent.

The manner in which the filter is operated is as follows: At the end of a run, or immediately before starting the filter, the filter-bed is washed thoroughly by forcing up through the screens and filter-bed a reverse flow of filtered water under pressure, the mechanical rake or agitator being operated at the same time, which adds materially to the efficient cleansing of the filter-bed. The water is forced up through the bed and the agitator is kept in motion until the water flowing from the overflow drain pipe is as clear as it was before being used for washing the filter. The necessary valves are then operated, and the unfiltered water, to which the sulphate of alumina is being added, is turned on the filter. The sedimentation basin is washed out by allowing the wash water at the top of the filter-bed to pass down into the basin through the central pipe shown in Fig. 2, Plate IV, and thence out through a waste pipe at the bottom of the basin. The agitator shaft runs through the central pipe and carries at its lower end a curved nozzle. As the agitator shaft is revolved, the nozzle is given a circular motion, and the rapid current of water passing through it is thrown to all parts of the sedimentation basin and stirs up and flushes out the accumulated sediment. The sedimentation basin is also provided with a manhole.

The averages of the results of Tables Nos. 1, 2 and 3 show that by the process of filtration there was:

99.20% less bacteria in the filtered water than in the raw water;
6 % less total solids in the filtered water;
1 % less chlorine in the filtered water;
61 % less ferric oxide in the filtered water;
38 % less aluminic oxide in the filtered water;
29 % less free ammonia in the filtered water;
63 % less albuminoid ammonia in the filtered water;
83 % less color in the filtered water;
20 % increase of hardness in the filtered water.

Table No. 4 shows that in every instance the filtered water was more or less alkaline, and, consequently, that the raw water was sufficiently alkaline to more than decompose the 1 grain per gallon of sulphate of alumina added to it.

Special attention is also called to the fact that Table No. 1 shows that the average number of bacteria per cubic centimeter found in the samples of filtered water is less than 5, and that the above summary shows that the filtered water contained 38% less alumina than did the raw water before the sulphate of alumina was added to it.

TABLE No. 1.—BACTERIOLOGICAL ANALYSES OF SAMPLES, BY DR. GARDNER T. SWARTS.

Results obtained during the time that 1 grain of sulphate of alumina per gallon was used.

Rate of filtration, 125 000 000 galls. per acre per 24 hours.

Date.	Bacteria per Cubic Centimeter.		Percentage of Reduction.	Date.	Bacteria per Cubic Centimeter.		Percentage of Reduction.
	Raw Water.	Filtered Water.			Raw Water.	Filtered Water.	
Mar. 13........	768	4	99.49	Apr. 27........	422	9	97.87
" 14........	595	5.5	99.08	" 28........	280	2.5	99.11
" 15........	Sterilized filter-bed.			" 29........	370	6	98.38
" 16........	1 299	9	99.31	May 8........	266	9	96.62
" 17........	1 257	7	99.45	" 9........	976	3	99.69
" 18........	683	4	99.41	" 10........	708	13.5	98.09
" 31........	782	1.5	99.82	" 11........	150	5	96.66
Apr. 1........	499	7	98.60	" 12........	466	3.5	99.25
" 3........	636	1.5	99.76	" 13........	305	4	98.69
" 4........	628	2	99.68	" 15........	225	1	99.56
" 5........	545	4	99.27	" 16........	238	0.5	99.79
" 6........	855	3	99.65	" 17........	306	0.5	99.83
" 7........	1 910	19	99.01	" 18........	473	0	100.00
" 8........	1 009	6.5	99.36	" 19........	210	0.5	99.76
" 10........	1 175	6.5	99.45	" 20........	228	1	99.56
" 11........	943	9.3	99.01	" 22........	238	0.5	99.79
" 12........	1 443	9	99.38	" 23........	279	1	99.64
" 13........	336	4.3	98.73	" 24........	228	1	99.56
" 14........	Lost.	4	....	" 25........	275	0	100.00
" 15........	798	1.6	99.84	" 26........	270	0.5	99.81
" 17........	765	7.5	99.02	" 27........	185	1	99.46
" 18........	578	1.5	99.74	" 29........	454	4.5	99.01
" 19........	865	11	98.73	" 30........	334	11.5	96.56
" 20........	546	3	99.45	" 31........	458	10	97.82
" 21........	699	2	99.71	June 8........	331	4	98.79
" 22........	499	3	99.40	" 9........	494	5.6	98.86
" 24........	293	3	98.98	" 10........	341	6.3	98.15
" 25........	697	0.5	99.93	" 12........	354	0.3	99.92
" 26........	724	11	98.48	" 13........	243	2	99.18
				Averages......	570	4.5	99.20

Special experiments were made from March 20th to 30th, from May 1st to 6th and from June 1st to 7th.

The bacteria in the different samples were cultivated during periods of from five to six days.

The results of the special experiments mentioned are shown in Table No. 5.

As may be noticed, the percentage less of bacteria from May 1st to 6th, when ¾ of a grain of sulphate of alumina per gallon was used, is considerably less than it was from March 20th to 25th, when the same quantity of sulphate of alumina was being used. The difference may be accounted for partially by the fact that the average number of bacteria

TABLE No. 2.—CHEMICAL ANALYSES OF SAMPLES, BY PROFESSOR JOHN HOWARD APPLETON.

Results obtained during the time that 1 grain of sulphate of alumina per gallon was used.

Rate of filtration, 125 000 000 galls. per acre per 24 hours.

The numbers express parts (by weight) in one million parts of water (by weight).

Date.	Total solids.	Total hardness.	Chlorine.	Ferric oxide.	Aluminic oxide.	N as free ammonia.	N as albuminoid ammonia.	N as nitrates.	N as nitrites.
				RAW WATER.					
Apr. 6.......	39.0	16.0	4.8	0.58	0.47	0.04	0.22	0.60	Trace.
" 13.......	39.3	14.0	7.0	0.60	0.80	0.10	0.26	0.90	"
" 20.......	39.9	17.0	6.4	0.61	1.05	0.05	0.26	0.70	"
" 27.......	43.7	18.0	6.2	1.00	0.75	0.02	0.22	0.70	"
May 11.......	53.1	21.0	6.4	0.91	1.84	0.03	0.38	0.60	0
" 18.......	54.9	21.0	6.1	1.01	0.34	0.03	0.34	0.60	Trace.
" 25.......	49.6	20.0	6.4	1.09	0.76	0.04	0.32	0.60	"
Averages......	45.6	18.1	6.2	0.83	0.86	0.04	0.29	0.67	....
				FILTERED WATER.					
Apr. 6.......	38.9	22.0	4.8	0.61	0.44	0.04	0.10	0.60	Trace.
" 13.......	40.4	19.0	6.0	0.45	0.55	0.05	0.11	0.70	"
" 20.......	37.4	22.0	6.4	0.28	1.02	0.05	0.10	0.60	"
" 27.......	39.6	19.0	6.2	0.19	0.26	0.01	0.07	0.60	"
May 11.......	47.2	23.0	6.3	0.20	0.55	0.02	0.14	0.40	0
" 18.......	49.8	23.0	5.8	0.13	C.47	0.03	0.12	0.50	Trace.
" 25.......	46.5	24.0	7.2	0.40	0.45	0.02	0.13	0.60	"
Averages......	42.83	21.7	6.1	0.32	0.53	0.03	0.11	0.57	....
				AVERAGE PERCENTAGE, MORE OR LESS, IN THE FILTERED WATER.					
	6% —	20% +	1% —	61% —	38% —	29% —	63% —	15% —	....

in the raw water was nearly five times as large from March 20th to 25th, when the more favorable results were obtained, than it was during the period of less favorable results, from May 1st to 6th; but the principal cause is due to the sample of filtered water of May 4th having contained a larger number of bacteria than was found in any

sample during the test, viz., 61, and as the sample of raw water of this date contained but 298, the percentage of reduction was only 78.89; which, being averaged up with the percentage of the other five days, brought down the total average of the special test, from May 1st to 6th inclusive, to 94.03 per cent.

The results given in Tables Nos. 1, 2, 3 and 4, are remarkably satisfactory; but on account of several instances in Table No. 1, when the bacterial reductions are shown to be below 98%, it may be well to state that the filter has been working at a disadvantage for a comparison by percentages, on account of the small number of bacteria in the raw water.

TABLE No. 3.—Color of Samples. Determined by Dr. Gardner T. Swarts.

Results obtained during the time that 1 grain of sulphate of alumina per gallon was used.

Rate of filtration, 125 000 000 galls. per acre per twenty-four hours.

Date.	Raw water.	Filtered water.	Date.	Raw water.	Filtered water.	Date.	Raw water.	Filtered water.	Percentage of color removed.
Mar. 13	0.30	0.06	Apr. 13	0.50	0.10	May 11	1.00	0.10	....
" 14	0.30	0.06	" 14	0.50	0.10	" 12	1.00	0.10	....
" 15	Sterilized filter-bed.		" 15	0.50	0.10	" 13	0.90	0.10	....
			" 17	0.50	0.10	" 15	0.80	0.10	....
" 16	0.30	0.06	" 18	u.60	0.10	" 16	0.90	0.10	....
" 17	0.30	0.06	" 19	0.60	0.10	" 17	0.80	0.10	....
" 18	0.30	0.06	" 20	0.60	0.10	" 18	o.80	0.10	....
" 31	0.40	0.10	" 21	0.60	0.10	" 19	0.70	0.10	....
Apr. 1	0.40	0.10	" 22	0.60	0.10	" 20	6.70	0.10	....
" 3	0.40	0.10	" 24	0.60	0.10	" 22	0.70	0.10	....
" 4	0.40	0.10	" 25	0.60	0.10	" 23	0.60	0.10	....
" 5	0.40	0.10	" 26	0.60	0.10	" 24	0.60	0.10	....
" 6	0.40	0.10	" 27	0.70	0.10	" 25	0 70	0.10	....
" 7	0 40	u.10	" 28	0.70	0.10	" 26	0.60	0.10	....
" 8	0.40	0.10	" 29	0.60	0.10	" 27	0.60	0.10	....
" 10	0.50	0.10	May 8	0.70	0.10	" 29	0.60	0.10	....
" 11	0.40	0.10	" 9	0.70	0.10	" 30	0.60	0.10	....
" 12	0.50	0.10	" 10	0.70	0.20	" 31	0.50	0.10	....
						Average	0.58	0.10	83.0

As can be seen by Table No. 1, the average number of bacteria found in the filtered water is less than 5 per cubic centimeter, which is a remarkably small number (the average number found in the effluent of the filter of the Lawrence water-works during March and April, 1898, being 28). Therefore, if the results given in Table No. 1

should be used for comparison with results obtained with other filters, the small number of bacteria found in the filtered water should be duly taken into consideration, as well as the percentages of reduction.

TABLE No. 4.—ALKALINITY OF SAMPLES. DETERMINED BY DR. GARDNER T. SWARTS.

Results obtained during the time that 1 grain of sulphate of alumina per gallon was used.

Rate of filtration, 125 000 000 galls. per acre per 24 hours. The alkalinity is expressed as calcium carbonate in parts per 1 000 000.

Date.	Raw water.	Filtered water.	Date.	Raw water.	Filtered water.	Date.	Raw water.	Filtered water.
Mar. 13	5.5	1.7	Apr. 13	10.2	Lost	May 11	14.0	6.0
" 14	7.5	2.0	" 14	11.5	4.0	" 12	14.5	6.5
" 15	{ Steri filter-	lized beds	" 15	11.5	5.0	" 13	14.5	5.5
			" 17	12.0	4.5	" 15	15.0	5.5
" 16	6.7	1.5	" 18	11.0	4.0	" 16	14.0	5.0
" 17	7.0	2.0	" 19	11.0	4.5	" 17	14.5	6.5
" 18	6.7	2.0	" 20	12.0	2.0	" 18	14.5	6.0
" 31	9.0	2.7	" 21	11.0	4.5	" 19	14.0	6.0
Apr. 1	8.5	3.0	" 22	8.5	4.7	" 20	14.5	6.0
" 3	9.2	2.7	" 24	14.0	7.0	" 22	14.0	8.0
" 4	9.5	3.2	" 25	14.0	7.0	" 23	14.0	6.0
" 5	8.7	3.2	" 26	14.0	6.0	" 24	14.0	7.0
" 6	6.5	3.0	" 27	14.0	6.0	" 25	14.0	7.0
" 7	11.0	3.7	" 28	14.5	6.0	" 26	15.0	6.0
" 8	10.0	3.2	" 29	13.5	6.0	" 27	14.5	5.0
" 10	9.0	3.7	May 8	15.0	6.5	" 29	14.0	5.0
" 11	10.5	3.2	" 9	14.5	6.0	" 30	14.0	5.0
" 12	11.0	4.0	" 10	15.0	6.0	" 31	14.5	6.0

TABLE No. 5.—RESULTS OF SPECIAL EXPERIMENTS.

Date. (Inclusive.)	Sulphate of alumina used. Grains per gallon.	NUMBER OF BACTERIA.		Percentage less bacteria in filtered than in raw water.	Percentage less color in filtered than in raw water.
		In raw water.	In filtered water.		
March 20th to 25th.	0.75	1 768	28	98.32	79
March 27th to 30th.	0.60	875	9	98.75	73
May 1st to 6th......	0.75	360	19	94.03	75
June 1st to 7th.....	1.00*	640	15	96.82	..

* Sulphate of alumina of low grade, containing 17.53% of Al_2O_3.

Experiments have shown that some species of bacteria will multiply even in distilled water that has been sterilized; and it is quite possible that, should sterilized water be applied to the filter instead of the raw water, a few bacteria might be found in the effluent as it flowed from the filter, as it would probably be impossible to keep any practical

filtering medium, or water which had been exposed to the atmosphere, completely sterile during the process of filtration.

The disadvantage under which the filter has been working is in accordance with the supposition that a few bacteria may, at times, grow in a filter and be carried through it during the process of filtration. These few bacteria would, in ordinary practice, be counted among others found, if there were such, in the filtered water. Now, if there were 2 000 bacteria per cubic centimeter in the raw water, and a small number per cubic centimeter should grow in the filter, they might not appreciably affect the percentage of reduction, owing to their number being relatively very small in comparison with the number in the raw water. If, however, the number of bacteria that grew in the filter was the same, and there should be 200 or 300 per cubic centimeter, for instance, in the raw water, instead of 2 000, the percentage of reduction might be affected considerably, as the small number that grew in the filter might bear an appreciable proportion to the 200 or 300 in the raw water.

The cost of operating the filter since it was first put in service has been practically the cost of the sulphate of alumina used, as no additional labor has been required, other than that already employed at the pumping station. The cost of operating, therefore, based upon 1 grain per gallon, and, considering the best grade of sulphate of alumina used during the test, would be $2.15 per 1 000 000 galls. of water filtered.

The total cost of the filter plant (shown on Plate IV) is estimated to be about $11 500. If the three additional filters, for which the filter house was designed, should be added, as has been mentioned previously, at the same cost per filter as the one which has been installed, the cost of the completed plant, representing a capacity of 2 000 000 galls. per 24 hours, would be about $21 000, or at the rate of $10 500 per 1 000 000 galls.

The East Providence Water Company is more than satisfied with the filter plant, and the customers of the company are much pleased with the filtered water, the appearance of which is practically the same as that of distilled water.

DISCUSSION.

GARDNER S. WILLIAMS, Assoc. M. Am. Soc. C. E. (by letter).—It would be interesting to learn whether the samples for analysis were taken from the filtered-water well shown in Fig. 2 of Plate IV, or from a tap above the floor. Judging from the illustration it seems hardly probable that if taken from the latter they would represent the condition of the water supplied to the consumers, and if they were taken from the well it does not seem possible that they can represent the conditions for any great length of time. Mr. Williams.

Many know the ease with which dust and filth, not to mention liquids, will pass through timber floors. From the drawings or the description of the plant, there does not appear to be any provision made for preventing the passage of such accumulations, as well as the coagulant that might be spilled upon the floor, through into the filtered water. It would be surprising to learn that this important point has been really overlooked, but if it has, the filtration of this supply must be one of the greatest farces of which we have had a record, however well satisfied the consumers may be with the water furnished.

GEORGE W. FULLER, Assoc. M. Am. Soc. C. E.—This paper is an interesting one, in that it adds to the meager data now available with reference to the purification, by this method, of waters which are soft and also at times quite highly colored. Owing to the fact that the views of water-works men are not well crystallized as to the best method of treatment for waters of this type, the subject is an important one for discussion. Mr. Fuller.

In connection with the results of this test, as presented in the paper, there are a number of points upon which it is desired to make comments and inquiries, as follows:

Color of the Raw Water.—One of the most important lines of information, from a practical standpoint, in connection with the purification of water of this type, is to have a reliable record of the color which it contains, due to organic matters dissolved in it. These data are as requisite for water of this class as are records of turbidity and amounts of suspended matter in the silt and clay-bearing waters of Western rivers. With this method of purification, color records bear directly upon the amount of sulphate of alumina required; the margin of alkalinity; the required provisions for coagulation and subsidence; and the percentage of wash water.

The paper does not state the method by which the recorded results were obtained; but, in a pamphlet issued recently by the New York Filter Manufacturing Company on this same subject, it is noted that the color results were obtained by the Nesslerized ammonia scale. The

Mr. Fuller. speaker thinks that the use of this scale is unfortunate for this line of work, for the reason that it is not a progressive one, and that the amounts of color for successive tenths on this scale are quite variable. That is to say, the individuality of the scale obscures the relationship between color and several factors of practical value, as noted above.

The question of color standards has been investigated thoroughly at several places, and was discussed fully by Desmond FitzGerald, President, Am. Soc. C. E., in the 1893 report of the Boston Water Board. For this line of work the platinum-cobalt standard is much more desirable for yielding data of practical value. A comparison of the two color scales, according to Mr. FitzGerald, is as follows:

Nesslerized Ammonia Scale.......	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
Equivalent on Platinum Scale....	0.18	0.26	0.33	0.39	0.46	0.52	0.58	0.63	0.70	0.81

From this table it is seen that according to the more consistent platinum scale the recorded results for the raw water are too high, and for the filtered water they are too low.

As color refers properly only to dissolved matters, the results would also be abnormally high in the raw water if it possessed turbidity which was not removed prior to reading.

Relations between Color and Required Sulphate of Alumina.—The available evidence indicates that, when the raw water contains more color than is removed with the use of 0.75 to 1.00 grain of sulphate of alumina per gallon, it is necessary to add this chemical in the approximate ratio of about 2 grains per gallon for 1 part of color in the raw water when the latter is expressed on the platinum scale. Sulphate of alumina in this case would be the ordinary grade, containing approximately 17% of alumina soluble in water, or having about 80% of the strength of the grade used in the East Providence test.

Keeping in mind the relationship expressed above, there are found, upon studying the data recorded in this test, two points upon which the speaker would be pleased to obtain further information, as follows:

1. As the amount of coagulating chemical was applied to the raw water regardless of whether the latter contained 0.3 or 1.0 part of color on the Nessler scale, the indications are that there was considerable waste of chemical in the former instance.

2. The practically complete removal of color when it was highest in the raw water by 1 grain of sulphate of alumina appears to be decidedly out of line with what little evidence there is available upon this subject.

Alkalinity.—Here again the paper does not state by what method the analytical results were obtained, but from a recent article in *The Engineering Record* it is learned that they were obtained with the aid of methyl orange as an indicator. This procedure, as applied to this particular test, is a very questionable one, in that this method, even

when the composition of the indicator used is such as to make it as sensitive as possible, is incapable of showing the presence of undecomposed sulphate of alumina in the filtered water. In fact, experience shows that if the filtered water should contain several grains per gallon of undecomposed coagulating chemical it is quite probable that with this indicator the filtered water would be recorded as slightly alkaline, notwithstanding the fact that it would be markedly acid if properly tested by reliable indicators, such as lackmoid and erythrosine. Mr. Fuller.

With the grade of sulphate of alumina used in this test it is probable that on an average about 9 parts of alkalinity are required to decompose 1 grain per gallon of the applied chemical. Turning now to the table of alkalinity results as recorded in this paper, it is noted that for a period of several weeks the raw water ordinarily contained rather less than this required amount when treated with 1 grain. From this evidence it would appear very probable that the filtered water contained undecomposed sulphate of alumina in small amounts with considerable regularity at that time.

Relation between Color and Alkalinity of Raw Water.—In connection with the purification of water of this type, it is of especial importance to ascertain the minimum alkalinity of the raw water and the color which it possesses at such times, and also the amount of alkalinity at times when the water is colored most highly. By this means alone can it be foretold definitely what the probable chances are of meeting the inadmissible state of affairs of having undecomposed coagulating chemical in the filtered water, and whether or not it is necessary at times to resort to the practice of making applications of alkali to the water during treatment.

At East Providence the data are very meager in this respect, as they are in almost every other instance of soft, colored waters, within the speaker's knowledge.

Chemical Results.—The principal point in connection with the results of the ordinary chemical analyses of water before and after filtration is the reduction of the nitrogen in the forms of free and albuminoid ammonia, which, as found elsewhere, is seen to be quite marked; and leaving in all probability only such organic matter in the filtered water as is so stable in its composition that it has practically no significance from a hygienic standpoint.

The reduction in the total solids and in the ferric and aluminic oxides is explained normally by the removal of the silt and organic matter of the raw water. Concerning the determination of aluminic oxide, there is very little reason to believe that it throws light upon the presence of undecomposed chemical in the effluent.

The other determinations, as recorded, ought not to show any difference in the results between the raw and filtered water. The

Mr. Fuller. increase in total hardness is abnormal, as ordinarily the reduction in carbonate hardness corresponds exactly to the increase in sulphate hardness, thus giving the same total.

Bacterial Results.—It will be noted that the numbers of bacteria in the filtered water are very low indeed, as judged by evidence from other filter plants, and this is of course explained very fully by the thorough coagulation of the raw water, which ordinarily must have been obtained with the liberal amount of sulphate of alumina which was used. In this connection, the speaker would like to inquire as to the reaction of the culture medium which was used, and also the temperature at which the bacteria were cultivated.

Growths of Bacteria.—From page 78 one would gather the idea that it is suggested that growths of bacteria within the filter might explain in part the presence of some of the very few bacteria which the filtered water contained. The evidence indicates that this idea, in connection with the East Providence results, has very little to substantiate it, for the following principal reasons :

1. The opportunities for growth in the sand layer of a mechanical filter are very much less than in the sand layer of an English filter, because, ordinarily, the former is washed and agitated at least once a day, removing thereby the majority of the bacteria which are attached to the sand grains, and especially those bacteria which are most favorably located with reference to food supply.

2. While it is true that the bacterial results of the effluents of English filters frequently show to quite a marked degree the results of bacterial growth within the sand layer, the fact that in this particular mechanical filter the rate of filtration was something like 50 times as great as is ordinarily the case in English filters would cause such a dilution of the few bacteria which might possibly grow on the sand, that it would appear to cause this factor to drop out of comparative significance in the connection in which it is used.

Wash Water.—The records of this test, as given in the paper, contain no statement with reference to the frequency of washing the sand layer, and the amount of water required for that purpose. This is an important matter in the test of a mechanical filter, and especially so where it is used with a fairly high-colored water, and in which there is provided only 17 minutes' time as an average period of coagulation and subsidence prior to the entrance of the water into the filter proper. The speaker would like to inquire if there are any data upon this topic.

Automatic Controller.—The automatic controller described is one of the most interesting features of the plant from a mechanical standpoint, and it would be interesting to know what head it requires for its normal operation, and what the pressure of the filtered water upon it was at the end of the run, where it is recorded that the variations in the rate were less than one-half of 1 per cent.

Cost of Operation.—It would seem that in this connection the item of wash water should appear. Obviously it had some value as applied under pressure at the bottom of the sand layer in connection with the agitation of the latter. Mr. Fuller.

With a filter of this type the cost of labor, in efficient operation, is ordinarily a considerable item. Although no additional labor may be required in this particular instance, it would seem only reasonable that there should be a *pro rata* charge against this item, as the filter plant doubtless increases materially the amount of work for the pumping station attendants.

E. Sherman Gould, M. Am. Soc. C. E.—The question of filtration of water is becoming a very important one, upon which no hydraulic engineer at present can afford to be uninformed. The speaker has been very much interested in this paper and in Mr. Fuller's remarks, and he thinks there are a number of points which could, with great interest, be elucidated in regard to this question. As between the slow, sand filtration and mechanical filtration, the prevailing idea seems to be that the former is preferable; that that is the standard method of filtration. But the great area which is required for the filtration of a large supply of water, and the necessity which seems to exist in the climate of the greater part of the United States for covering these filters, makes the proposition somewhat formidable. If anything quicker, smaller and cheaper can be devised, it will be a very great benefit, and, as far as the speaker can judge from his reading of what is going on throughout the country, mechanical filtration seems to be coming very much into prominence on this very account. In recent reports by a very high authority, upon the filtration of certain supplies to which the speaker's attention has been called, it is stated that exactly the same purification would be obtained whichever system was used. If that can be established as a fact, the mechanical system of filtration certainly has much to recommend it. Mr. Gould.

The speaker would like to be informed on one point which would seem to constitute a possible superiority of the mechanical filter. Although, in the slow sand filtration, by far the greater part of the purification is effected on the upper quarter-inch or half-inch of the fine sand, and in the gelatinous film which is formed by the water itself, that the lower courses of the filter, the coarser sand, the gravel, the coarse gravel, and through all the gradations, do exercise some refining and purifying influence on the water. Therefore, if those beds toward the bottom filter the water to some extent, they must retain some of its impurities. Now, as far as the speaker knows, the cleaning of a sand filter is limited entirely to the removal of the upper quarter-inch, half-inch, or inch, or whatever it may be, of the top surface, and he has not yet seen any account of the removal, cleaning and replacing of the entire filtering material, whether it be 3, $3\frac{1}{2}$ or 4 ft. deep. If all the

Mr. Gould. filter is filtering, and thereby retaining impurities in greater or less quantity, it would seem that all the material should be renewed occasionally. But, when the mechanical filter is washed, all the material is washed; the whole filter from top to bottom is cleaned, and that might be a point of superiority. Is the period during which a sand filter bed is laid off for the purpose of having the surface scraped long enough to accomplish the purification of the rest of the filter by aeration? Has it ever been found necessary in sand filters to remove occasionally the entire material and clean it? If so, it must increase greatly the cost of operation and maintenance.

Mr. Currier. CHARLES G. CURRIER, Assoc. Am. Soc. C. E.—Filtration of water on a large scale is gradually becoming a necessity for various of our communities, and the skilled hydrologist knows how to recognize this better than politicians. Many a supply, which appears excellent to those who judge merely by the clearness, the taste, the color, and even by the results of chemical testing of a few samples, is regularly or irregularly a means of bringing disease to a varying proportion of those who drink it; while a supply may be highly colored and contain much "impurity" and still be harmless, as, for instance, that from the "Dismal Swamp," which years of experience have shown to be wholesome. The Croton water-shed yields an excellent water if we judge it by the mortality statistics of New York City, although it seems somewhat bad at times to citizens or visitors who happen to see vegetable detritus which appears at certain seasons.

So, too, an expert would condemn it if any considerable area of the water-shed was so much like a sewer and receptacle for refuse as the tributary stream which flows through Brewsters. The beneficent processes of Nature, operative during the interval after the water leaves this region of fouling and in storage and flowing gently onward diluted by more wholesome water, serve to minimize greatly the danger coming from contamination there. Yet sanitary engineering work is needed there and elsewhere, and public filtration of the entire Croton supply would make it more satisfactory, although other cities stand more in need of the process.

Sand filters have been in use in England for more than half a century. Until about sixteen years ago they were not recognized as having other than the obvious merit of clarifying water and producing some chemical improvement in it. At Berlin, where this method had been introduced in 1856, extensive new beds were constructed in 1883, for the Tegel river-lake supply, to strain out the growths of *crenothrix* which, owing to the presence of iron in the supply, developed so extensively as to obstruct the pipes. At that time the recently developed Koch nutrient-gelatine method of testing for bacteria was tried and soon revealed the fact that such filters, when working properly, had the great hygienic merit of holding back almost all the bacteria,

besides all visible impurities which abounded in the crude supply. This admirable result was found to be due to the dense film of minute vegetation, silt and other fine sediment which is caused to settle upon the top of the freshly cleaned upper layer of fine sand before any water is allowed to filter through. Some chemical improvement also takes place especially in the upper portion as the water passes through, though Frankland classes this as "slight," and, from the point of view of disease-prevention, this is wholly unimportant as compared with the practically complete arrest of any bacteria capable of inducing typhoid fever or other water-borne disease. * Mr. Currier.

It should be stated that—despite a number of special methods for isolating typhoid bacteria—it is nowadays not regarded as practicable, regularly, to detect these bacteria in water; and the advertisers who, after examination of a given sample of water, assure people that their supply is free from the germs of typhoid, ought not to be relied upon.

As with the very few varieties of domestic filters, such as the "Berkefeld" and the "Pasteur," which are capable of rendering a water germ free, so with all other filters for rendering water fit to drink, the essential quality is the mechanical straining action produced by a dense obstacle between the crude supply and the wholesome effluent. In sand filters the continuous surface film must, as above indicated, be produced and maintained perfect and unbroken. Otherwise, the product is unfit for use in case there be any disease germs in the crude supply. For "mechanical" filters, in all of which, like that described by Mr. Weston, the water flows through a relatively small bed of sand fifty to sixty times as fast as is the safe rule with the slow, gravity sand beds, and which are cleansed and renew their films many times, while the slow filters are making a single run of days or weeks, it is necessary to add a suitable coagulent, such as iron salts, or, more commonly, alum sulphate. One part of this latter salt, or even a little more, to 100 000 parts of crude water is usually added during the entire flow, and, to insure a satisfactory film, most operatives add considerably more than this to the first water let in at the beginning after each washing. In reply to the question as to whether the very minute amount of undecomposed alum, which is present in the effluent of a successfully managed mechanical filter, is in any way detrimental to health, or objectionable in any industry, it may be said that no sufficient evidence can be adduced against the careful use of alum in this way.

In testing numbers of different makes of mechanical filters under various conditions during the last decade, the speaker has found them to vary considerably in efficiency. When they were well managed and not overworked they were found capable of yielding results compar-

* *Transactions*, Am. Soc. C. E., Vol. xxiv, pages 40 to 58.

Mr. Currier. able with those of the best slow gravity sand beds. But altogether too often the operatives are careless, even if the plant be adequate and the appointments good. When not at their best they are inferior to good gravity beds. When yielding regularly such an excellent effluent as is represented by Mr. Weston's figures, even though the cost of operating be considerably greater than he indicates, they would be preferable to the large, slow sand-bed filters in places where suitable location for the latter type is not available, or where fine sand of the right sort is not readily obtainable at moderate cost. The usually lesser first cost of the plant, as compared with that of the large, slow beds, when well constructed, is an influencing element. Against them may be urged that their constant efficiency depends too much upon the persons operating them, and that defects in the hygienic quality of the effluent cannot be detected until that has got beyond reach in a general reservoir, if not already consumed. For each properly constructed slow gravity bed, on the other hand, separate storage basins are now in favor, and these can retain the effluent of a given filter bed until the usual test has shown whether the water is to be used or wasted.

As Mr. Fuller has remarked, the increase of one-fifth in hardness shown in the paper is contrary to the rule and must depend on some element not explained therein. The extent of bacteriological purification is notable. In answer to one of the queries it is proper to state that the very competent gentleman who tested for bacteria, in all probability used the familiar Koch's gelatine culture test, and his experience and reliability should cause one to give full credence to his report. When for three months of constant practical use of the filter the effluent reveals to this test less than ten bacteria for every thousand which were in the crude water, that is a very good showing. Yet the best slow gravity beds would be likely to show less fluctuation than is evident from the latter half of Table No. 3 and in Table No. 5 (May 1st to 6th). It is fair to assume that this same filter would have developed a still higher ratio of efficiency if in the same crude water the number of bacteria had been as high as occurs in some other unfiltered waters.

In considering water-filtration results, too much relative importance is still attached to the "chemical purification." The presence of ammonia in the filtrate does not in itself mean any menace to perfect wholesomeness. Good distilled water may show a far greater proportion of this than occurs in any natural supply. So, too, near the sea coast or in a saline region chlorine is to be expected in water supplies to a degree in excess of the average amount elsewhere. But it is hygienically of absolutely no importance that this is found to be reduced 1% or even much more in the effluent of this or other excellently working filters. If the iron is lessened three-fifths and the color more than four-fifths (tested in any constant, acceptable way) and the

water thereby rendered more acceptable, that, of course, appeals to the users and is in so far a benefit. But what they do not appreciate, and what is nevertheless of paramount importance, is the immense amount of bacteria kept out of the purified supply by the best filters, and with which any chance disease germs are also held back and annihilated. Some waters, apparently quite wholesome, have a considerable number of bacteria, and on the other hand, waters can be infected with the germs of typhoid fever and other diseases and yet have a relatively low number of bacteria of all kinds. It is not of itself the mere quantity so much as the nature of the bacteria present which makes the element of positive danger in a drinking water. Since the separation of practically all the bacteria of a bad or questionable water supply means also the removal of all germs of disease, that should be the ideal and practical result always aimed at. If with this an exceptional degree of chemical purification is achieved, so much the better. Inasmuch as the nutrient-gelatine culture test is simple and easy to carry out by careful people, even if they be not at all familiar with laboratory technique, that valuable test should be used regularly in a uniform way in connection with the operation of all filters. Mr. Currier.

EDMUND B. WESTON, M. Am. Soc. C. E. (by letter).—The writer has read Mr. Fuller's discussion with a great deal of interest. Mr. Weston.

The color data given in Table No. 3, from March 13th to 18th, inclusive (5 days), as originally furnished the writer, were incorrect. Instead of 0.30 for the raw water and 0.06 for the filtered water, the figures for the 5 days should read 0.50 for the raw water, and 0.10 for the filtered water.

The writer, of course, did not propose to do chemical work in regard to the subject in hand. As to chemical matters, he is aware that different chemists sometimes hold different views on a given subject.

The chemical work was referred to Professor John H. Appleton, of Brown University, a gentleman whose age, long experience and conservative judgment entitle his opinions to great weight; and the writer still feels entire confidence in the analytical work, and the opinions expressed by Professor Appleton in the chemical questions involved in this discussion.

Color of the Raw Water.—Mr. Fuller remarks that the paper "does not state the method by which the recorded results" on color were obtained. They were obtained by the platinum-cobalt method.

Mr. Fuller remarks that "in a pamphlet issued recently by the New York Filter Manufacturing Company * * * , it is noted that the color results were obtained by the Nesslerized ammonia scale." Mr. Fuller misunderstands the pamphlet. The pamphlet states what "the unit of color" is; but does not state the "method." The platinum-cobalt method was used, but the unit of color of this method

Mr. Weston. is, as the pamphlet states, "practically that color yielded by properly Nesslerizing 50 c. c. of water containing one-hundredth of a milligram of ammonia gas (or its equivalent)." It appears, therefore, that Mr. Fuller's inferences with respect to the color data are not in accord with the facts.

Relation between Color and Required Sulphate of Alumina.—It was desired, if the alkalinity of the water would permit, to obtain a bacterial removal of at least 99% without regard to the quantity of sulphate of alumina used. It was found that 1 grain of sulphate of alumina per gallon would do this without rendering the filtered water acid; and it was also found that when $\frac{3}{4}$ of a grain was used, the bacterial removal was less than 99 per cent. It was therefore decided to use 1 grain.

As to Mr. Fuller's inference that there was a considerable waste of chemical at times, Mr. Fuller probably intended the statement to be taken in a relative sense, as the whole amount of sulphate of alumina used daily was not considerable, averaging less than 28 lbs., the daily cost being about 46 cents.

It should be remembered that the filter was in practical service during the test, and was not being run as a laboratory experiment; and as the bacterial removal averaged more than 99%, and the color of the filtered water was hardly distinguishable from freshly distilled water, and was sufficiently alkaline to show that the quantity of sulphate of alumina was being kept within the proper limit, it would hardly have been practicable, even if a small quantity of the sulphate could have been saved, to have made, from time to time, minute changes in its amount, as the cost of the labor of doing so would have been of much more account than the cost of the sulphate of alumina which might have been saved. Then, if this refinement had been gone into, and an experienced person had been employed to have continually kept the run of the alkalinity of the water, the expense would have been many times greater than the cost of the whole of the sulphate of alumina used.

It would appear as though Mr. Fuller's inferences from his experience with the water of western rivers would not apply to river waters in the vicinity of Providence.

During the Providence filtration experiments, in 1893 and 1894, it was demonstrated that the percentage of color removed from the raw water could not be relied upon as a gauge, in respect to the removal of bacteria, and the results of the East Providence test show the same to be the case.

At East Providence, as has previously been stated, the paramount desire was to remove at least 99% of the bacteria from the raw water, provided that it could be done without exhausting the alkalinity of the water and causing the filtered water to be acid, the importance

of the removal of the color from the raw water being regarded as secondary to that of the bacteria. Mr. Weston.

As the bacterial results for each day were not known until about five days afterward, on account of the time required for cultivation, it would not have been possible to have gauged accurately the quantity of sulphate of alumina, more or less, which might have been the most advantageous to have used each day; therefore, as experience had shown that ¾ of a grain of sulphate of alumina would not produce an average bacterial removal of 99%, and that 1 grain would accomplish the desired result, and as the filtered water was always alkaline when 1 grain was used, it was thought that the constant use of 1 grain per gallon was the most satisfactory method of applying the sulphate.

Alkalinity.—Mr. Fuller makes a considerale body of comments on the alkalinity of East Providence water. The writer discusses these comments briefly:

The alkalinity determinations were made as follows: two portions, each of 500 c. c., of the water were placed in flat white porcelain trays side by side. To each sample, 5 c. c. of solution of methyl orange was added. First one sample and then the other was titrated with standard sulphuric acid, the acid being so prepared that each cubic centimeter would neutralize 1 part per million of calcium carbonate in 500 c. c. of water. (The sulphuric acid solution was standardized by pure sodium carbonate; then its value in calcium carbonate was computed.)

Mr. Fuller objects to methyl orange as an indicator. The writer must rely on Professor Appleton's statement that methyl orange is, in fact, a sensitive indicator for acid and alkali, that it is widely used for this purpose, and is recommended by high authorities on water analysis. Indeed, it was used during the elaborate filtration experiments conducted under the direction of Allen Hazen, Assoc. M. Am. Soc. C. E., at Pittsburg, Pa.; and Mr. Hazen appears to have been entirely satisfied with the reliability of the alkalinity determinations made with methyl orange.

From certain experiments made elsewhere by Mr. Fuller, he forms the opinion that the filtered East Providence water, during a portion of the test, must necessarily have been acid. But this is an opinion. As the result of actual tests, the filtered water was alkaline. That is, a considerable quantity of the standard sulphuric acid was necessary to overcome its alkalinity.

Mr. Fuller states that, in his opinion, a filtered water might "contain several grains per gallon of undecomposed" sulphate of alumina, and yet that such water might be slightly alkaline to methyl orange. In the East Providence filtered water there could not possibly have been several grains per gallon of undecomposed sulphate of alumina, since not more than 1 grain was added to the raw water.

Mr. Weston. *Chemical Results.*—Mr. Fuller appears to represent that the analytical determinations of alumina, Al_2O_3, in the raw and the filtered waters are of little account. The writer holds the opposite view. He thinks them of considerable importance. They certainly show that in all cases the amount of alumina, Al_2O_3, in the filtered water was very small. It varied from about 0.02 to about 0.06 of a grain per gallon. But the 1 grain of sulphate of alumina added in the coagulant contained 0.22 of a grain of alumina, Al_2O_3. It is plain, therefore, that at least a considerable part of the alumina, Al_2O_3, contained in the sulphate of alumina applied, was removed by the process of filtration. Then, again, the analytical determinations show that there was an average of 38% less alumina, in the filtered water, than in the raw water before the sulphate of alumina was added to it. The writer considers these interesting and important facts.

Bacterial Results.—The culture medium used was 10% gelatine, and the reaction was slightly alkaline. The bacteria were cultivated at the average refrigerator temperature, the temperature of the laboratory being high at all times.

Growths of Bacteria.—The writer fears that he did not make his possible solution sufficiently clear, and that Mr. Fuller has interpreted his intent rather too broadly. It occurred to the writer, upon three or four occasions when the number of the bacteria in the filtered water had increased in a much greater proportion than those in the raw water, that it might have been due to a few bacteria growing in the filter. It was not his intention, by any manner of means, to even suggest the inference that bacteria ordinarily propagate in mechanical filters as they do in slow sand filters.

Wash Water.—From records kept during March, April and May, while 1 grain of sulphate of alumina, containing about 22% of Al_2O_3, was being used, the average length of the runs of the filter, which is the period between washings, is shown to have been about 6.6 hours; the range being from about 5 to about 9 hours.

During these runs, the height of the surface of the water in the filter (which remains practically constant), was about 10.85 ft. above the surface of the water in the controller. The operating head, or the head consumed during the process of filtration, was about 10.25 ft., namely: the difference between the level of the water surface in the filter and the elevation of the water (corresponding to the head upon the inlet pipe of the controller), above the surface of the water in the controller at the time the filter was shut down for the purpose of being washed. Immediately after washing, at the commencement of a run, about 2.92 ft. of the operating head was lost by friction, due to the water passing through the clean filter-bed, screens and outlet pipes.

On account of the desirability of supplying the raw water to the

filter by gravity, the filter was made only 12 ft. high, which is 4 ft. less than the standard height of filters of the Jewell gravity type, of the capacity installed at East Providence. If the filter had been 16 ft. high, the standard height, the operating head would have been 4 ft. more than 10.25 ft., and, consequently, as the greater the operating head, other things being equal, the longer a filter will run, the average length of time between washings would have been longer than 6.6 hours. Mr. Weston.

As the filtered water is being pumped constantly from the filtered-water well into the mains, it would be inconvenient to measure the amount of wash water used each time the filter is washed. From several measurements which have been made, however, the indications are that the average quantity of wash water used does not exceed 4% of the total amount of water filtered.

Automatic Controller.—The operating head, during the test referred to by Mr. Fuller, was 9.35 ft., and the head upon the inlet pipe of the controller at the end of the test was equivalent to a height of 1.5 ft. above the water surface of the controller.

The preliminary tests of the class of controllers used at East Providence are made with heads ranging from 18 ft. above the surface of the water in the controller as a maximum, to 0.33 ft. as a minimum.

Cost of Operation.—The wash pump is driven by a water turbine wheel, of much greater power than is necessary, which had been installed for another purpose before the filter plant was contemplated, and as the East Providence Water Company owns the water privilege from which the water required to operate the turbine is derived, the writer hardly thinks it would be advisable for him to go to the expense of indicating the power required to drive the pump, although, as a matter of scientific interest, he would like to know what it is. He can state, however, that a test, made about two months ago, showed the maximum horse-power of the water pumped while washing the filter-bed to be about 14. The horse-power was computed by considering the maximum quantity of water pumped per minute, the water pressure at the discharge end of the pump, and the elevation of the pump above the water in the filtered-water well. If the filter had been 16 ft. high instead of 12 ft., the other conditions being equal, the horse-power would have been about 15.6.

The pumping engineer, who has charge of the filter plant, estimates that the cost of the labor required for taking care of it is about $0.50 per day. As the writer has already stated in the paper, no additional labor, other than that which was employed before the filter plant was built, is required to take care of the filter plant. This $0.50, considering the present consumption of about 200 000 galls. would equal, proportionately, $2.50 per 1 000 000 galls. Of course the cost per 1 000 000 galls. would be proportionately reduced if the filter was

Mr. Weston. running the entire 24 hours and delivering its full capacity of 506 000 galls., and it would be very much less per 1 000 000 galls. if the three other filters, for which the filter building was designed, were installed, and running at their full daily capacities.

In reply to Mr. Gould—the general practice in England appears to be, after the repeated scrapings of a filter-bed have reduced its depth to the minimum limit, to dig off the old sand in sections above the gravel and replace it with a layer of fresh or washed sand, the old sand then being filled in upon the clean sand.

The advantage of being able to sterilize the filter-beds of mechanical filters, the writer considers to be of much importance.

The writer appreciates highly the thorough manner in which Dr. Currier has treated the subject in his carefully prepared and instructive discussion.

All processes of filtration, to be successful, must have intelligent supervision. Professor Percy Frankland, whose connection with the London water companies is well known, states, in regard to slow sand filtration:

"But the responsibility which we have seen attaches to this treatment of water cannot be exaggerated, for whilst when efficiently pursued it forms a most important barrier to the dissemination of disease germs, the slightest imperfection in its manipulation is a constant menace during any epidemic."

Professor William P. Mason, of Troy, N. Y., has stated, in regard to the subject:

"A filter, of whatever type, is a more delicate piece of apparatus than is generally recognized, and it requires constant attention of the most careful kind. In the mechanical form of filter, this care must, of necessity, be constantly forthcoming, or the filter would not run a day; the English bed, on the other hand, may be, and to my knowledge is, at times grossly neglected, and that too where the volume of the supply would seem to call for more attentive supervision."

The samples of filtered water, to which Mr. Williams refers, were taken from the controller and not from the well.

It would seem, by the somewhat eccentric language used by Mr. Williams, that he has derived considerable satisfaction, in drawing from a small outline sketch some rather humorous inferences in regard to the construction of the filter building.